# Electrokinetic Transduction of Acoustic Waves In Ocean Sediments

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## LONG-TERM GOALS

Electrokinetics (EK) and surface chemistry play an important role in wave propagation in electrolyte-saturated porous media and certain kinds of suspensions.  The sea floor exhibits acoustical properties usually attributed to both of these material types.  This project seeks to understand how EK phenomena and wave propagation are coupled in ocean sediments.

## OBJECTIVES

The immediate goal is to better model sediment behavior and wave propagation in the $1 - 500$ kHz frequency band which has important applications in subsurface acoustical imaging, Mine Counter-Measures, and Anti-Submarine Warfare.  To obtain essential experimental data to support the modeling effort, it is necessary to develop experimental techniques for EK sound generation and reception in various porous materials.

## APPROACH

The common working hypothesis is that the sea floor acts as either a (possibly viscoelastic) fluid or elastic solid.  This diverges from the experimentally measured, frequency-dependent behavior of ocean sediments [1].  And yet there is no completely accepted model of mechanical—nor in particular, acoustic—motion in ocean sediments.

The Biot theory of poroelastic media captures much of the sediment physics left out by other models [2].  It fits experimental data well and is therefore a candidate for use in propagation modeling [3].  Biot theory predicts two kinds of compressional waves: a fast wave, described by in-phase motion of the pore fluid and (porous) solid skeleton, and a slow wave, described by out-of-phase motion.  Relative motion between the pore fluid and grain structure produces sound speed dispersion and attenuation, generally in the $1 - 10$ kHz frequency band.  This phenomena is seen experimentally.  Direct detection of relative fluid motion (and slow waves, in particular) would validate the use of Biot

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14. ABSTRACT
**Electrokinetics (EK) and surface chemistry play an important role in wave propagation in electrolyte-saturated porous media and certain kinds of suspensions. The sea floor exhibits acoustical properties usually attributed to both of these material types. This project seeks to understand how EK phenomena and wave propagation are coupled in ocean sediments.**

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theory in sea floor acoustics. Unfortunately, slow wave motion is heavily damped and difficult to observe using acoustic transducers.

Biot theory, extended to include chemical and electromagnetic forces, indicates that relative fluid motion and slow wave propagation are directly related to electrokinetic phenomena [4,5,6]. An EK transduction technique for studying slow waves is being developed to take advantage of this fact. *EK-Transmission* occurs when an applied voltage drives ionic—and thus fluidic—currents in an electrolyte-saturated material. Conversely, *EK-Reception* is possible when fluid electrolyte motion in this material creates a measurable voltage. In concert with the coupled EK-Biot equations, these experimental techniques will shed new light on the validity of Biot theory as a model of ocean sediments.

Each of these approaches has both experimental and theoretical parts. The experiments, described in the next section, are small in scale. Since EK phenomena are known to occur in porous media, in addition to sand, loose glass microspheres and glass bead packs (as simulated Biot materials) will be used in the experiments. Theoretical modeling of the experiments is an essential requirement for comparing results from different material types. The timeline for this work extends from 2002 – 2005.

This project is Gareth Block's (long-distance) doctoral research at the University of Illinois at Urbana-Champaign, funded by a three-year ONR Special Research Award in Ocean Acoustics Graduate Fellowship. Gareth Block and Dr. Nicholas Chotiros are research scientists at the Applied Research Laboratories at the University of Texas at Austin, which provides the facilities and support for this work. Professor John G. Harris, from the University of Illinois at Urbana-Champaign, and Dr. Chotiros are co-advising Mr. Block.

**WORK COMPLETED**

This research may be divided into the following components: (1) Modeling the physical processes of wave motion and EK phenomena in porous materials, sediments, and suspensions based on existing theories and models. (2) Development of the required experimental apparatus for generating and measuring voltage potentials in electrolyte-saturated sand. (3) Generation of acoustic waves using EK-Transmission techniques. (4) Measurement of voltages in an insonified sample using EK-Reception techniques. (5) Comparing measurements and model predictions to assess the validity of existing models and possibly develop new, improved models.

Significant work has been accomplished on points (1), (2) and (3) above. Our first task was to perform a thorough study of existing literature pertaining to Biot and electrokinetic theory. The important concepts and governing equations of coupled EK-Biot theory are described in Pride [4] and have been applied to seismology and material characterization [5,6]. Apparatus constructed for both EK-Reception and EK-Transmission experiments are shown on the left and right sides of Figure 1, respectively. The experimental apparatus and results for EK-Transmission are discussed in the next section. Experimental work for EK-Reception will begin in 2003. Theoretical (and numerical) results for the case of EK-Reception were obtained by solving boundary value problems to guide design of the experiment. Current theoretical work for EK-Transmission is focused on expanding the coupled EK-Biot model to include thermoelastic (ThE) effects.

**RESULTS**

EK-Transmission experiments have so far utilized a high voltage source (and capacitor bank) connected to a pair of closely separated gold post electrodes buried in a NaCl solution-saturated sand. Care was taken not to induce a plasma discharge, but rather to generate a short current pulse. Acoustic pressure created by this current flow is measured using a buried 1-3 composite PZT transducer about 10 cm from the electrodes. The voltage drop between the buried electrodes has two effects. First, current flow through the sediment tends to heat the pore fluid locally, creating a ThE wave. Since this heating is due to the power dissipated, the amplitude of ThE pressure waves depends on the square of the applied current. We first compare the peak received pressure to the peak applied current for experiments run in solutions of various conductivities. A quadratic dependence on current is found when the experiments are run in sea water alone (for a large range of resistivities) as shown in the top plot of Figure 2.

The second effect of generating a large voltage drop in electrolyte-saturated porous materials is to create an EK pressure. EK is a linear coupling of the ionic current flow and electric field to the Biot mechanical fields (in the simplest case, EK-Biot theory is simply a combination of Ohm's and Darcy's laws). In the EK-Transmission experiment, the goal is to measure the extent to which a linear dependence on current is found. This indicates that the sediment grain structure supports relative fluid motion. In this context, the sediment behaves as a Biot material. In the bottom plot of Figure 2, the slope of the received pressure (as a function of applied current) is found to vary strongly with resistivity of the pore fluid. A transition between EK- and ThE -dominated regimes occurs as the resistivity is decreased. Current analytical and numerical work is focused on predicting this dependence.

**IMPACT/APPLICATIONS**

EK generation and reception of acoustic waves may yield new methods of measuring the material properties of the sea floor. Using the coupled EK-Biot model already described, we might use EK techniques to determine properties of ocean sediments such as permeability, volume fraction and tortuosity *in situ*. These Biot parameters are critically important and difficult to measure. Other models which reliably predict wave propagation in *non-Biot* granular materials, extended to include EK phenomena, may also yield properties of the sediment microstructure. These are new capabilities that we currently do not possess. They will have a significant impact on our ability to model sound propagation and penetration into the seabed in applications involving Anti-Submarine Warfare, Mine Counter-Measures, and sonar performance models. Similarly, ocean environmental models (used in tandem with acoustic inversion) can be checked and corrected as necessary.

**TRANSITIONS**

No transitions have been made at this time.

**RELATED PROJECTS**

Electrokinetic techniques are commonly used to measure the chemical properties of colloids. In seismology, EK techniques have been used to image sandstones and other Biot media [5]. EK phenomena are also used as a basis for characterizing the porosity and permeability of porous samples in the laboratory [6].
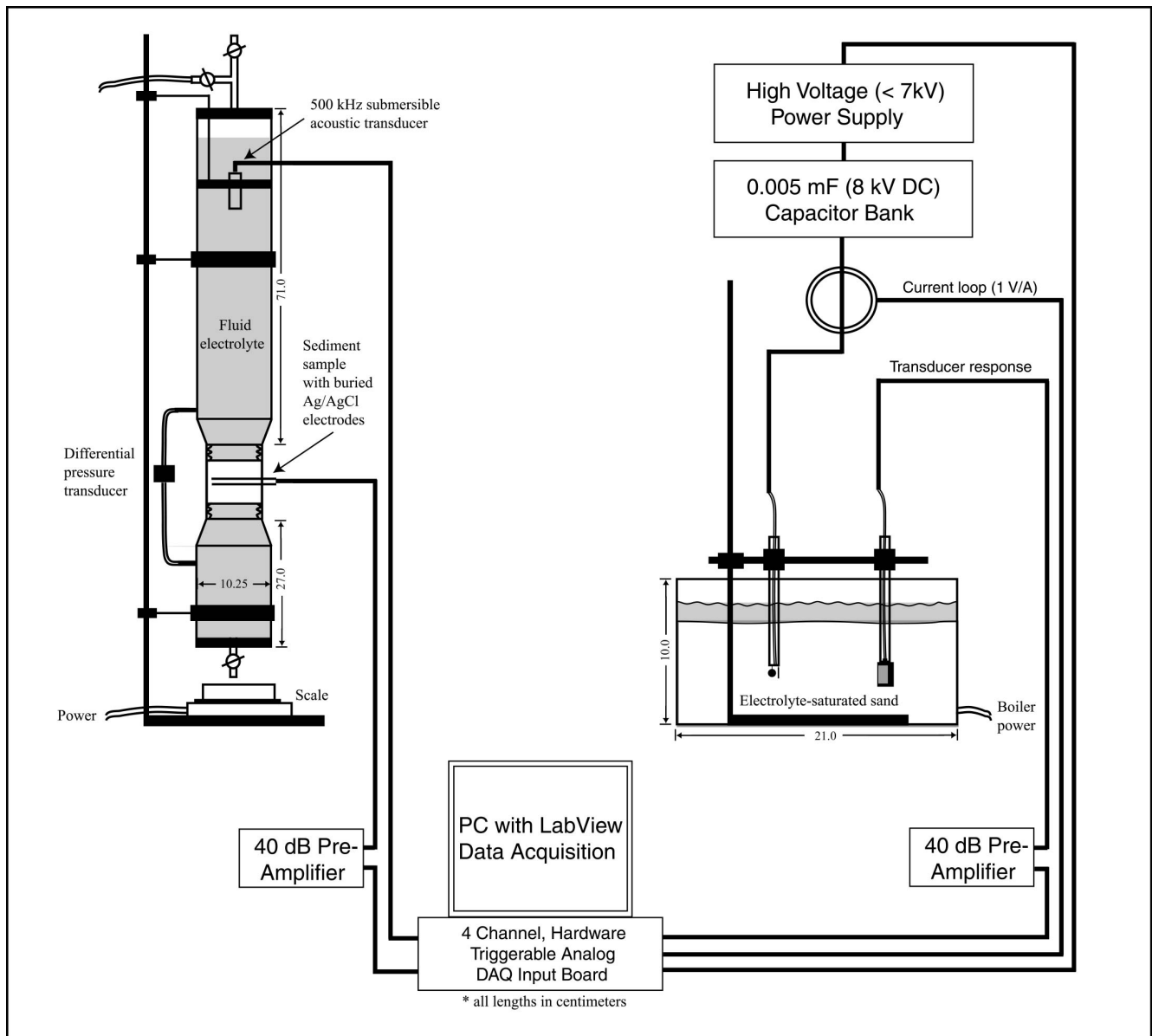
***Figure 1. Electrokinetic-Biot Transduction Apparatus***
*[EK-Reception Apparatus (left): A submerged acoustic transducer generates a pressure wave which impinges on the sediment sample from above. Special Ag/AgCl electrodes, buried within the sample, pick up measurable EK voltages due to relative fluid motion. (DC measurements of EK phenomena are also possible.) EK-Transmission Apparatus (right): A high voltage source connected to buried gold electrodes produces both thermoelastic and electrokinetic pressures. Different electrode geometries produce different effects. A 1-3 composite receiving transducer is buried in the far-field.]*
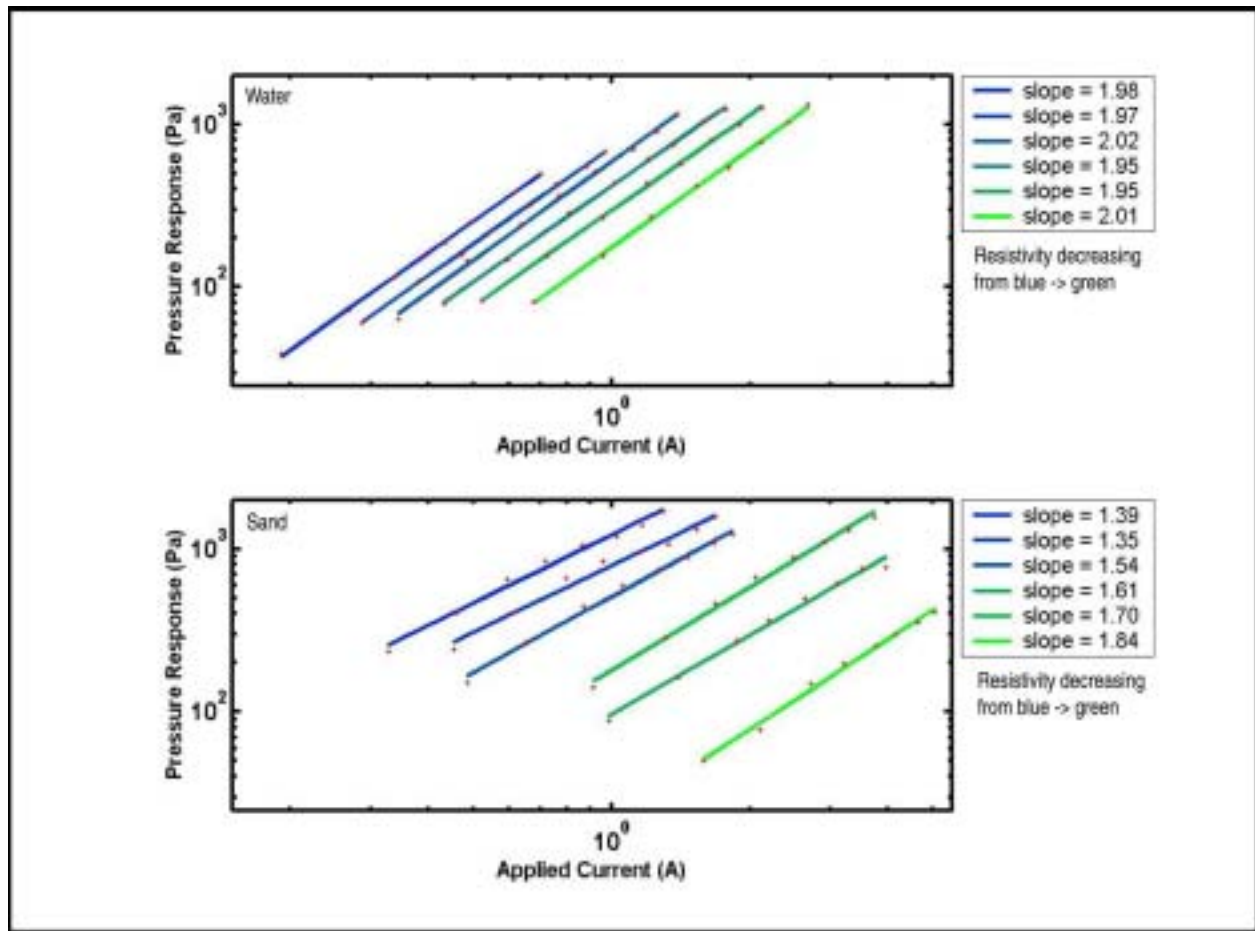
***Figure 2. Impulse-Response of Water and Electrolyte-Saturated Sand***
***[graph: The power law in salt water shows a simple quadratic dependence on current over a***
***resistivity range of 0.5 – 5.0 Ωm. In the electrolyte-saturated sediments used here, the slope varies***
***between 1.35 and 1.84 as the resistivity decreases (from blue to green). The slopes of each power-law***
***fit to the data are shown in the legends.]***

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